AN OVERVIEW OF MODELLING FINE-SCALE VARIATION IN ENVIRONMENTAL REGIMES IN COMPLEX LANDSCAPES WITH COMMENTS ON APPLICATIONS TO INVERTEBRATE SURVEY, MONITORING AND CONSERVATION

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Spatial and temporal variation in environmental regimes such as thermal, radiation and hydrologic conditions can influence invertebrates in many ways including the survival and performance of species, their biogeography, patterns of alpha and beta diversity, and their role in various essential ecosystem processes. Combinations of environmental regimes are known to be significant determinants of habitat quality for many invertebrates but, until recently, the technical ability to model fine-scale environmental heterogeneity in the landscape has been limited. In this paper I discuss some recent developments in modelling environmental heterogeneity at scales apparently sufficient to provide habitat discrimination for a number of invertebrate taxa, and comment on the potential application of these techniques to invertebrate biodiversity conservation. ☐*Invertebrates, biodiversity, conservation, environmental gradient, predictive modelling, geographic information system, conservation reserve network.*

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Australia signed the Convention on Biological Diversity on World Environment Day in 1992, at the Earth Summit in Rio de Janeiro, and ratified it on 18 June 1993. The convention was developed in recognition of the present and future value of biological diversity and its significant reduction around the world. The intention of the Convention is to be a powerful catalyst for drawing together existing issues to protect biological diversity and to provide strategic direction to global efforts in this area (DEST, 1993).

Many approaches can be adopted for the conservation of biological diversity. The general approach adopted in many nations involves, in principle, the use of conservation reserves complemented by off-reserve management practices (e.g. codes of practice) that aim to minimise significant detrimental impacts on biological diversity. Where necessary, additional measures such as ex-situ conservation and the reintroduction and translocation of species may be used to support conservation objectives. For this general conservation strategy to be effective, it is important that (i) the reserve system be representative of the full range of biological diversity in the nation of concern, (ii) the reserve system be sufficiently comprehensive and adequate to be viable over at least the medium term, (iii) off-reserve management prescriptions be sufficiently conservative to allow for uncertainties arising from limited biological knowledge; and (iv) research and ecological monitoring programs be in place so that it is possible to learn from the successes and failures of various management prescriptions (Common & Norton, 1993). A number of new programs have been initiated nationally and internationally to address these needs, including the National Reserves System Cooperative Program (NRSCP) which involves the progressive establishment of a comprehensive national system of protected areas in Australia by the year 2000.

Because scientific knowledge of most taxa and assemblages is limited, the selection of additional conservation reserves will typically be based on environmental data and limited biological data. The latter data will primarily be for vascular plants and vertebrate fauna. Given this, three important questions arise regarding invertebrate biodiversity conservation:

(1) to what extent can environmental, vegetation and vertebrate fauna data be reliably used as surrogates for data on invertebrate biodiversity?

(2) is it possible to determine which invertebrate taxa might be well and poorly represented by such data?

(3) given the above, what is the most effective way of enhancing the effectiveness of invertebrate biodiversity conservation in the short, medium and long term?

The purpose of this paper is to discuss the potential for applying spatial modelling techniques that have been developed to characterise environmental regimes at various spatial scales to invertebrate biodiversity surveys and conservation evaluation.

MODELLING ENVIRONMENTAL REGIMES IN COMPLEX LANDSCAPES

One aim of ecology is to better understand the biological patterns, particularly the distribution and abundance of taxa, that occur within terrestrial ecosystems and the processes that effect these patterns. By enhancing this understanding data on biota will be acquired that can be used immediately for conservation planning and management. In addition, these data can be used to improve ecological theory and help develop a process based understanding of natural systems to permit the more reliable prediction of system dynamics.

The concepts underlying the spatial modelling of environmental regimes and their use for developing a process understanding of biological systems have been well discussed by Nix & Gillison (1985), Norton et al. (1990) and Moore et al. (1993). Contemporary studies of the processes effecting the distribution, productivity and interactions between biota along environmental gradients are likely to be more informative if these gradients are characterized more specifically and at a finer resolution than has typically been employed in the past. For example, rather than using elevation as a crude surrogate for spatial variation in temperature and/or precipitation in a region, it is more accurate to employ quantified gradients of these and other climatic attributes associated with elevation to model biological patterns. Similarly, rather than using estimates of spatial variation in mean annual temperature or rainfall, for example, as variables to model the distribution of taxa, it is more realistic to use climatic indices that more closely reflect the ambient conditions to which species are exposed (see Margules & Austin, 1991). This is now possible at a fine spatial scale using modern computer-based mathematical algorithms and spatial analysis techniques, coupled to spatially-related data sets including digital terrain models, to derive estimates of climate surfaces and various site attributes or indices of environmental processes that are considered indicative of landscape processes (Moore et al., 1993). Some of the environmental regimes that can be modelled include the surface energy budget (evapotranspiration, potential solar radiation); minimum, maximum and average air temperature, wind speed and wind run; relative soil water content or wetness index; soil mineral nutrients; hydrological properties of a catchment (e.g. rates of discharge and recharge); and, the potential biological productivity of a site.

Central to this modelling is an ability to derive reliable estimates of the terrain, climate, and substrate for large regions at relatively fine scales, and to manipulate and analyse these data quickly and efficiently. Digital elevation models (DEMs) have been developed by Hutchinson (1989) to interpolate topographic data and model spatial variation in terrain. The data used to develop these models can be in the form of (digitised) irregularly spaced point elevation data, major streamlines, natural sinks (eg. lakes) and the coastline. The techniques have been used to generate a continental DEM for Australia at a grid resolution of 1/40th degree longitude and latitude (2.5 × 2.5km) (Hutchinson & Dowling, 1991). DEMs at finer resolutions (i.e. a gridded database where each grid cell represents from 250 × 250m down to 1 × 1m on the ground) have been developed for several regions of the Australian continent for specific survey, inventory and land evaluation studies (e.g. Richards et al., 1990; Moore et al., 1993). Digital terrain models can be derived from a DEM to allow an estimate of slope, aspect and related topographic features of a landscape for each grid cell (Moore et al., 1991). These models and spatially related data sets are held with a geographical information system.

Climate surface fitting techniques developed by Hutchinson (1987) have enabled the estimation of spatially reliable mean (monthly, weekly, daily) climate attributes derived from long-term meteorological station records for any given longitude, latitude and elevation on the Australian continent and selected other regions. The errors associated with thes estimates are typically of the same order as those associated with observer and instrument errors.

Currently, techniques to estimate spatial variation in soil fertility are limited as soils data are not available at compatible resolutions for most of the Australian continent. Geological data mapped at a scale of 1:250 000 represents the best data available to estimate soil nutrient regimes at a landscape level, although soils data may be available for a number of areas. Mackey et al. (1988, 1989) reported a procedure to derive a spatial estimate of soil nutrient availability for relatively large regions by assigning a rating (0-10) to each lithological unit digitised from geological maps for a given region. The major assumption with this technique is that the soils in the specified region are largely derived from the parent material below and not formed through depositional processes, in which case the soils may be unrelated to the composition of the underlying bedrock.

Several additional data sets such as vegetation cover, data on the distribution of wildlife and site disturbance have been found to be useful for the survey, inventory, and management of various plant and animal taxa (Richards et al., 1990; Margules & Austin 1991; Nix & Switzer, 1991; Neave et al., 1992).

APPLICATIONS OF MODELLING TECHNIQUES

A number of applications of the techniques developed for modelling environmental regimes in complex landscapes have been published recently (see Neave & Norton, 1991). These applications include the characterisation of the spatial and temporal variation in the environmental regime of landscapes as a basis for the design (eg. stratification) of biological surveys, and the undertaking of biological modelling and conservation evaluation. For example, Austin & Heyligers (1989) outlined a systematic procedure using derived environmental regimes to stratifying the location of sites for the field survey and inventory of vascular plants in north east New South Wales. Similar approaches have been developed by Neave et al. (1992) for the inventory of diurnal birds in south east Australia, and Moore et al. (1993) in the Brindabella Range, Australian Capital Territory for characterising the realised niche of eucalypts.

Environmental regimes estimated for large regions were employed by Norton & Williams (1990), Lindenmayer et al. (1991), and Norton et al. (1992) to assist in the systematic collection of site-based data for building predictive models of the distribution of vertebrate fauna. In addition, this general approach has been suggested for assessing the potential viability of existing or proposed wildlife corridors under scenarios of global and climate change (Norton & Nix, 1991).

Booth et al. (1988) have used these techniques to quantify the realised niche of tree species to help in the identification of new sites best suited to grow species/genotypes or to identify the most suitable taxa to grow at a particular site (e.g. Booth et al., 1988). Mackey (1991) predicted the spatial variation in forest architecture and physiognomy of tropical rainforest vegetation in north east Queensland, Australia using this approach, while Nix et al. (1992) employed spatial estimates of environmental regimes and other site attributes to predict variation in site productivity and the rate of growth of eucalypts in Tasmania. It should be noted, however, that most of the above studies concern vascular plants, vertebrates and assemblages thereof. The use of these techniques for invertebrate conservation is limited (P. Cranston & M. Gray, pers. comm., 1993) but, I believe, has significant promise.

ROLE OF SPATIAL MODELLING FOR INVERTEBRATE CONSERVATION

Spatial and temporal variation in environmental regimes such as thermal, radiation and hydrologic conditions may influence invertebrates in many ways including the survival and performance of species, their biogeography, and patterns of alpha and beta diversity (Warren, 1985; Dobkin et al., 1987; Weiss et al., 1988; Kitching et al., 1993). Combinations of environmental regimes are known to significantly influence the habitat quality of many taxa but, until recently, the technical ability to model fine-scale environmental heterogeneity in the landscape has been limited.

It is now possible to estimate various environmental regimes at a fine spatial scale, across large areas. Moore et al. (1993), for example, modelled various environmental regimes (e.g. net radiation; maximum, average and minimum temperature; precipitation, soil water content, evapotranspiration) in a 21km^2 area in the sub-alpine forests in south east Australia using gridded data where each grid cell represented 20×20m on the ground. The authors used these data to investigate the environmental correlates of vegetation in the study area and found the average minimum temperature in the coldest month and the annual net radiation were two environmental variables differentiating the occurrence of several of the major tree species. More recently, this database has been extended to cover an area of 90km^2. Gridded environmental databases with a cell size of 100-200m exist for large regions including the wet tropics of north east Queensland, north eastern New South Wales and Tasmania. As a consequence it is now possible to investigate the extent to which these modelling approaches can be usefully applied for invertebrate biodiversity conservation. In particular, can environmental gradients in major environmental regimes be used to help design field surveys that are more effective in capturing the range of invertebrate biodiversity within target areas, or to monitor changes in invertebrate assemblages over time? Can these techniques be used to develop correlative models for predicting the distribution of invertebrate taxa?

As these sorts of issues are addressed it will be possible to quantitatively consider the three questions that I raised at the outset of this paper. It will be possible to test the extent to which patterns exhibited by plants and vertebrate taxa are congruent with those observed for invertebrates, and to establish the most appropriate scales at which to use these techniques for survey, analysis, conservation evaluation and management. In the context of invertebrate biodiversity conservation, a significant management question will presumably be how to proceed if the present surrogates (e.g. vegetation, vertebrates) that are used for conservation reserve selection and configuration are found to be completely inadequate. If this is the case, then appropriate off-reserve management will be very important requirement in the overall effort to conserve invertebrate biodiversity.

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